

Bringing light to the Landau-Lifshitz-Gilbert equation: Optically induced magnetic inertia and magnons

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The Landau-Lifshitz-Gilbert (LLG) equation has been the cornerstone of modeling the dynamics of localized spins, viewed as classical vectors of fixed length, within nonequilibrium magnets. When light is employed as the nonequilibrium drive, the LLG equation must be supplemented with additional terms that are usually conjectured using phenomenological arguments for direct opto-magnetic coupling between localized spins and (real or effective) magnetic field of light. However, direct coupling of magnetic field to spins is $1/c$ smaller than coupling of light and electrons; or both magnetic and electric fields are too fast for slow classical spins to be able to follow them. Here, we displace the need for phenomenological arguments by rigorously deriving an extended LLG equation via Schwinger-Keldysh field theory (SKFT). Within such a theory, light interacts with itinerant electrons, and then spin current carried by them exerts spin-transfer torque onto localized spins, so that when photoexcited electrons are integrated out we arrive at a spin-only equation. Unlike the standard phenomenological LLG equation with local-in-time Gilbert damping, our extended one contains a non-Markovian memory kernel whose plot within the plane of its two times arguments exhibits fractal properties. By applying the SKFT-derived extended LLG equation, as our central result, to a light-driven ferromagnet as an example, we predict an optically induced magnetic inertia term. Its magnitude is governed by a spatially nonlocal and time-dependent prefactor, leading to the excitation of coherent magnons at sharp frequencies in and outside of the band of incoherent (or thermal) magnons.

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